

## Chapter 2

# Introduction to the geography and geomorphology of the Andaman–Nicobar Islands

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**Abstract:** The geography and the geomorphology of the Andaman–Nicobar accretionary ridge (islands) is extremely varied, recording a complex interaction between tectonics, climate, eustasy and surface uplift and weathering processes. This chapter outlines the principal geographical features of this diverse group of islands.



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The Andaman–Nicobar archipelago is the emergent part of a long ridge which extends from the Arakan–Yoma ranges of western Myanmar (Burma) in the north to Sumatra in the south. To the east the archipelago is flanked by the Andaman Sea and to the west by the Bay of Bengal (Fig. 1.1). A c. 160 km wide submarine channel running parallel to the 10° N latitude between Car Nicobar and Little Andaman islands, known as Ten Degree Channel, is a major physiographic discontinuity that separates the Andaman Group to the north from the Nicobar Group to the south (Fig. 1.1). The Andaman Group, located c. 1200 km SE of the mainland in the Bay of Bengal, is sometimes also referred to as the Bay Islands. The Andaman–Nicobar chain forms a 700 km north–south arc with the convex side towards the Indian mainland, and occupies an area of c. 8249 km<sup>2</sup>. Within the literature there is a significant variation in the number of islands assigned to the Andaman Group, for example 212 islands (Karunakaran *et al.* 1964), 274 islands (Banghar 1987), and 319 (Bhoothalingam 1972) due to differences in distinction between rocky outcrops (islets) and islands. Currently 38 islands of the Andaman Group are inhabited. Great Andaman comprises the five largest islands of the Andaman Group: Baratang, Rutland, North, Middle and South Andaman islands. Duncan Passage separates Little Andaman from Great Andaman (Fig. 1.1). Ritchie's Archipelago NNE of Port Blair in the Andaman Sea comprises a cluster of small islands (including Havelock, Neil and Henry Lawrence Island, Fig. 1.1). East–west-running tidal channels (straits) flanked on both sides by thick mangrove forests separate the largest islands: the Austin Strait between the Middle and North Andaman; the Humphrey Strait between the Middle and Baratang islands; the Middle Strait between Baratang and South Andaman; and the Macpherson Strait between the South Andaman and Rutland islands. Of these, only the latter is navigable by ocean-going vessels. The Andaman Group also includes two islands of volcanic origin, Barren and Narcondam islands, located in the Andaman Sea NE and NNE of Port Blair, respectively (see Chapter 9 for details).

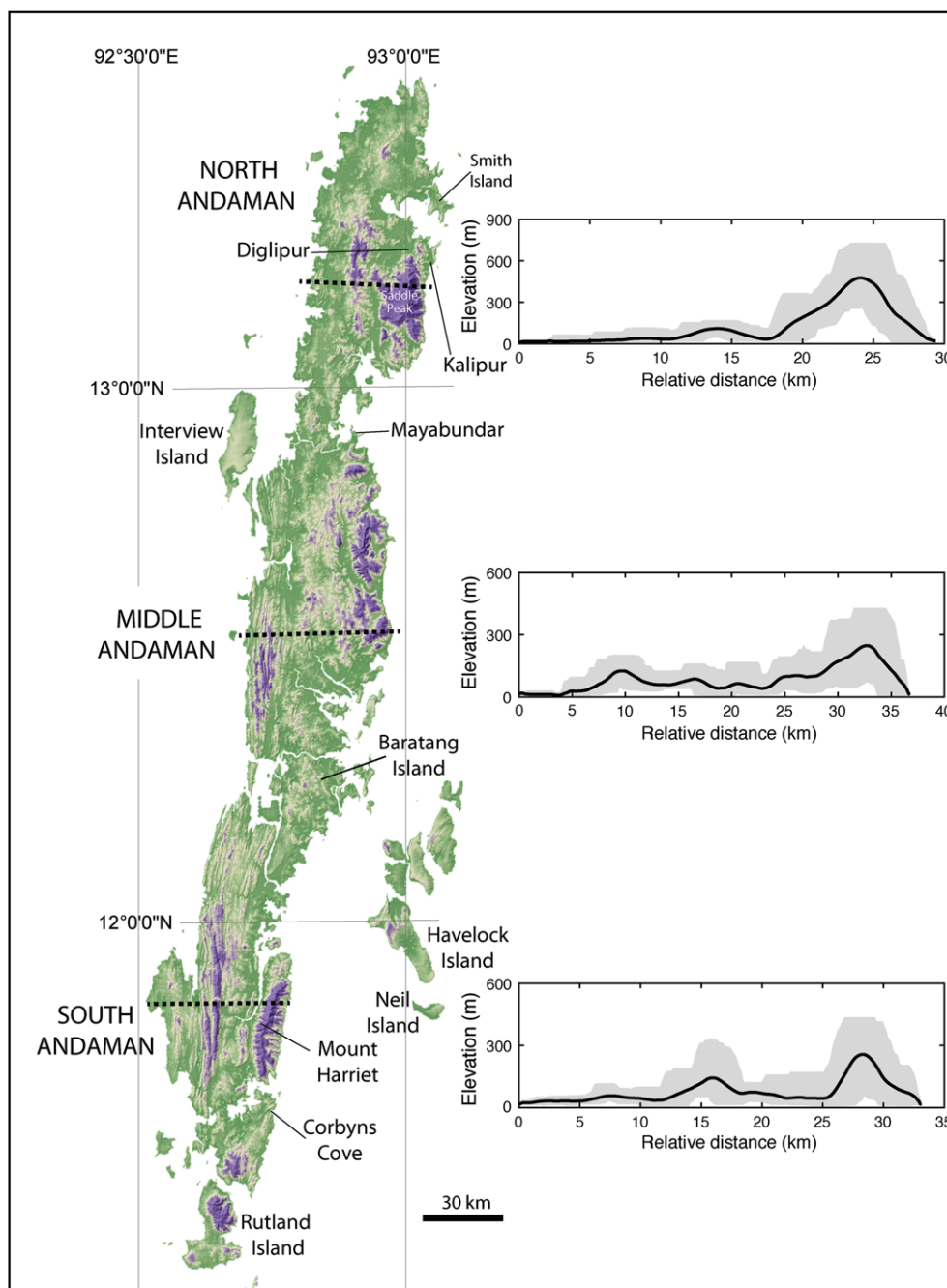
Lying south of the Ten Degree Channel in the eastern Indian Ocean the islands of the Nicobar Group are spread out over a distance of 259 km. They have a maximum width of about 58 km and cover an area of 1841 km<sup>2</sup>. In total there are 22 islands, of which 13 are inhabited (Fig. 1.1). The Nicobar islands are divided into northern, central and southern groups. The inactive Nicobar Fan (Bowles *et al.* 1978), a topographically isolated segment of the Bengal Deep-Sea Fan lies west of the Nicobar Group. Car Nicobar Island hosts the

administrative headquarters of the Nicobar Group. Other islands of importance are Katchal, Camorta, Nancowry, Tillangchong, Chowra, Little Nicobar and Great Nicobar. The latter is the largest covering 1045 km<sup>2</sup>. Indira Point on the south coast of Great Nicobar Island, named after the honorable Prime Minister Smt Indira Gandhi of India, lies 147 km from the northern tip of Sumatra and is India's southernmost point.

The highest point among the Andaman–Nicobar Group is Saddle Peak (733 m a.s.l.) on North Andaman (Figs 2.1 & 2.2). The second-highest point (713 m a.s.l.) occurs on the volcanic island of Narcondam (Fig. 1.1). Great and Little Nicobar are also hilly; Mount Thullier (642 m) on Great Nicobar is made up of parallel ridges of folded turbidite sandstones (Karunakaran *et al.* 1975). The east–west swath profiles in Figure 2.1 show that the eastern side of the Andaman islands contains most of the relief (Fig. 2.1) and the tallest peaks, which are formed from ophiolites and turbidite sandstones (e.g. Mount Harriet, c. 362 m, the highest peak on South Andaman). Although the hills on the western side are also formed from parallel ridges of Oligocene-aged turbidite sandstones, the topography is gentler and of lower elevation. Other important peaks include Sound Peak Hill (515 m high) behind Cuthbert Bay, Mount Angelica (469 m) and Mount Baker (371 m) on Middle Andaman and Mount Ford (Kala Pahar) (435 m) on Rutland Island.

Similar to most of the islands in the Bay of Bengal and Indian Ocean, the Andaman and Nicobar islands have a tropical to subtropical climate with typical humidities in the range 79–89% and daily temperatures of 27–33°C in the summer and 21–25°C in the winter. The archipelago also benefits from sea breezes that moderate these hot and humid conditions. Sets of the NE monsoon arrive in November followed by the SW monsoon towards the end of May. As a consequence Port Blair on South Andaman receives copious amounts of rainfall averaging 300–350 cm annually, mostly delivered by the SW monsoon which blows from May through September and by the tropical cyclones (Fig. 2.3) that follow in October and November (Chakravarthy *et al.* 1987). Rainfall is much lower in the Nicobar Islands; Car Nicobar averages 51 cm per year ([www.imd.gov.in](http://www.imd.gov.in), Hydromet Division, IMD, New Delhi). The Andaman Islands have long provided meteorological data for shipping in the Bay of Bengal; a weather station at Port Blair has been in operation since 1868.

Associated with the tropical climate is a lush vegetation. Most of the islands of the Andaman Group are covered by



**Fig. 2.1.** Digital elevation model showing variations in topography for the Andaman Islands. The swath profiles are based on a 3 km wide window.

dense forest exhibiting tall trees, often more than 30 m high, typical of tropical rain forests (Gupta 2011). Of the 8249 km<sup>2</sup> land area about 80% remains covered by forests, which are widely acknowledged as biologically diverse and of global significance with high species endemism. The vegetation of the Nicobar Islands is typically divided into coastal mangrove forests and the interior evergreen and deciduous tropical and subtropical moist broadleaf forests. Tidal creeks, vast areas of mangrove swamps and mud flats are other coastal features, and the Andaman Islands support one of the world's most extensive mangrove ecosystems covering an area of 929 km<sup>2</sup> (plus 37 km<sup>2</sup> on the Nicobars) (Andrews & Sankaran 2002). Due to the special and sometimes unique flora and fauna, 94 islands in the Andaman–Nicobar Group have been designated as sanctuaries and there are four national parks in the Andaman Group (Mahatma Gandhi marine park, Mount Harriet, Rani Jhansi marine park and Saddle Peak national park) and two national parks on Great Nicobar (Campbell Bay and Galathea).

### Economic development

According to the Indian census in 2011 the population of Andaman numbered 379 944. Most people are engaged in agriculture, farming bananas, rice, coconuts, betel (areca nuts), fruits and spices (such as turmeric). Rubber, oil palms and cashews are also important. Forestry was also one of the main sources of employment until 2002 when, in order to preserve the unique ecology of the islands, the Supreme Court of India ordered that commercial logging should cease and revoked the licenses of saw mills and wood-based industries. This change led the Island Development Authority to promote other areas for economic development including eco-tourism, deep-sea fisheries and deep-sea oil and gas exploration (see Chapter 11). Tourism, aided by daily air links between Port Blair and Chennai or Kolkata, is concentrated between October and April. Most tourists come from the Indian mainland, but a significant number of foreign tourists also visit the islands. Popular tourist attractions include the



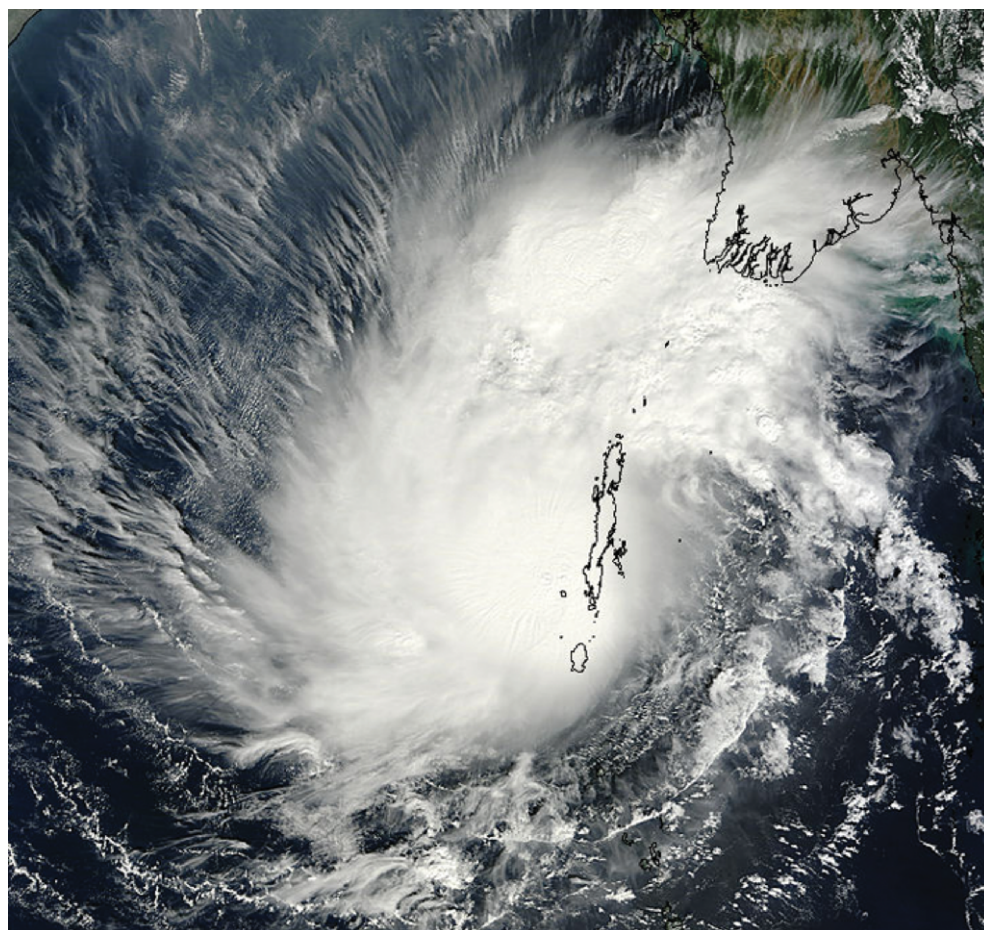
**Fig. 2.2.** Saddle Peak (733 m a.s.l.) on North Andaman Island viewed from Kalipur beach. In the foreground are mangroves and a tidal flat at high tide.

ruins of the British colonial administration in Ross Island, the Andaman Cellular Jail and the Chatham Saw Mills in Port Blair, and British summer home of the Chief Commissioner on the peak of Mount Harriet. Other natural attractions include the coral reefs and virgin beaches, as well as the limestone cave and mud volcanoes on Baratang Island.

### Water resources and hydrogeology

In terms of areal coverage, the exposed geology of the Andaman archipelago comprises around 70% Palaeogene

sedimentary rocks deposited on Upper Cretaceous sandstone, siltstone and shale and intrusions of basic and ultrabasic igneous rocks associated with a dismembered ophiolitic suite. The igneous rocks cover no more than 15% of the region, and the remaining rocks are mostly young coralline and limestone formations and colluvium. Despite their wide coverage, the Palaeogene sedimentary rocks are generally not a good source of water and the bulk of the fresh groundwater supply outside of the larger towns comes from springs or perennial streams associated with igneous rocks or limestones. The spring and stream catchments typically include hills of heavily fractured igneous rocks such as on Rutland Island, Panchavati Hills (Middle Andaman) and Saddle Peak (North Andaman).



**Fig. 2.3.** Tropical cyclone Lehar over the Andaman Islands on 25 November 2013. NASA Goddard MODIS Rapid Response Team.



Limestone-fed springs provide most of the water on Little Andaman and Havelock islands (Roy *et al.* 2014).

South Andaman is the most densely populated island and, although it has six perennial streams (Dhanikhari, Mithakhari, Badamnala, Burmanala, Premanala and Prothrapurnala), most of the water needs of the capital Port Blair are sourced from the largest stream, the Dhanikhari that supplies a 132 m long and 32 m high reservoir built by the British. The principal streams flow along the regional north–south-oriented structural trend of the Andaman accretionary ridge, and take an eastwards swing before merging into the Andaman Sea. Dhanikhari Nala in South Andaman Island flows from south to north for about 15 km from Chidiyatapu to Flat Bay before entering the sea. Middle and North Andaman have only one perennial stream each, the Rangat and the Kalpong, respectively. The only hydroelectric power plant of the Andaman–Nicobar archipelago harnesses the catchment area of the Kalpong River of North Andaman which flows towards the north for about 40 km before merging into the Andaman Sea near Aerial Bay in the east, near Diglipur. Great Nicobar has five perennial streams, namely the Galathea, the Jubilee, the Dak Aniang, the Dak Tayal and the Amrit Kaur, all originating from Mt Thullier. The Galathea is the longest river which flows for about 30 km towards the south and merges into the sea at Galathea Bay.

Due to a growing demand for fresh water from increased tourism and a rising population, increased attention has been diverted to exploiting groundwater resources, especially on the main population centre of South Andaman. The best aquifers tend to occur in fractured igneous rocks associated with the ophiolite basement. Fracture density has a greater control on availability of groundwater than drainage density, and the ophiolite rocks of Andaman have the highest areal fracture density (north–south-, east–west- and NE–SW-trending) compared to the more widespread sedimentary rocks. The

sedimentary rocks can be a source of water especially if deeply weathered, but in most cases transmissivities are low.

Over half of the South Andaman population live in the coastal areas, where freshwater sources are often locally dug wells and shallow boreholes. Coastal aquifers are vulnerable to ingress of saltwater due to the reverse hydraulic gradient associated with freshwater extraction, but this was not a major problem until the 26 December 2004 earthquake and tsunami. This event caused two changes. Firstly, it opened up new fractures at deeper levels that tapped into the mainly shallow (<30 m) aquifers, causing wells and boreholes to dry up or flow to cease. Secondly, aside from the tsunami which caused some temporary contamination along coastal areas, the earthquake caused seawater ingress and contaminated groundwater sources. This was partly caused by changes in coastlines associated with the regional tilting of the islands that subsided along the eastern coast and uplifted along the western side (see Chapter 10). The creation of new deep-seated fractures also lowered groundwater levels in some areas, allowing saline water ingress and mixing. Other phenomena reported at the time of the earthquake were saline water fountains on inland hills near Ravindra Nagar, Little Andaman and Jarawa creek on Baratang Island. Continuous monitoring of water quality of wells in the affected islands before and after the tsunami documented the affects of seawater contamination, with a change from low electrical conductivity to brackishness or relatively higher electrical conductivity in the post-tsunami period. Although some wells are gradually becoming less saline, they are not yet useable (Table 2.1). Not all islands were affected; on Neil Island Singh *et al.* (2005) found few changes among 105 wells.

Examples of well discharge rates are provided by the hydro-geological investigations of the Central Ground Water Board (CGWB) at Port Blair. Groundwater exploration carried out

**Table 2.1.** Changes in the salinity of shallow (<6 m) wells in tsunami-affected areas of Andaman and Nicobar, from Kar & Srivastava (2014)

Location	Well name	Pre-tsunami S.W.L (m), date, electrical conductivity in $\mu\text{S cm}^{-1}$	Post-tsunami S.W.L (m), date, electrical conductivity in $\mu\text{S cm}^{-1}$	Status
South Andaman, Port Blair	Peerless Beach Resort	(a) 3.20 (3.5.04) EC-320	(a) 1.25 (9.1.05) EC-6000	Brackish conditions persist
		(b) 1.74 (9.12.04) EC-330	(b) 1.32 (11.3.05) EC-6050	
			(c) 2.31 (27.4.05) EC-5850	
			(d) 1.13 (10.8.05) EC-2390	
			(e) 1.97 (22.2.06) EC-1830	
			(f) 0.74 (9.8.06) EC-1230	
			(g) 2.82 (4.4.07) EC-1820	
			(h) 1.72 (10.2.09) EC-1420	
			(i) 1.72 (27.11.13) EC-780	
Car Nicobar	Tapoiming Well	(a) 2.57 (22.2.02) EC-380	(a) 1.50 (9.2.05) EC-3290	Brackish conditions persist
		(b) 2.16 (6.6.04) EC-330	(b) 1.45 (18.2.05) EC-850	
			(c) 1.55 (15.7.05) EC-5060	
			(d) 1.25 (6.2.06) EC-1400	
			(e) 1.66 (10.4.07) EC-600	
			(f) 1.354 (11.8.08) EC-580	
			(g) 1.45 (10.11.13) EC-580	
Katchal Island, Nicobar	Kapanga	1.14 (5.2.01) EC-320	(a) 2.64 (4.7.05) EC-8390	Brackish conditions persist
			(b) 2.55 (20.7.06) EC-1700	
			(c) 2.66 (16.4.07) EC-2640	
Nancowry	Champin	1.50 (2.2.01) EC-350	(a) 2.03 (20.6.05) EC-3990	Brackish conditions persist
			(b) 2.17 (7.2.06) EC-2500	
			(c) 1.45 (19.7.06) EC-1700	
			(d) 3.11 (17.4.07) EC-3390	

S.W.L. is the standing (or rest) water level.



between 1984 and 91 included 47 exploratory bore wells. Six proved successful, of which five were drilled in ophiolites where fracture conduits were found at up to 45 m below ground level. The ophiolite-based Calicut well yielded a discharge rate of 45 000 L/hour. Alluvial deposits in stream valleys were also found to carry a lot of water throughout the year along the subsurface, and valley fills formed potential aquifers. One such valley fill at Beadonabad tested by a 17 m deep well had a discharge of 72 000 L/hour. Limestone formations on Car Nicobar, Katchal, Neil and Havelock islands have shallow aquifers. These are developed by digging 4–5 m diameter wells up to 6 m in depth. Typical yields vary over the range 15 000–90 000 L/day.

### The coast of the Andaman–Nicobar archipelago

The north–south-aligned Andaman–Nicobar Islands have east- and west-facing coastlines with a total length of 1962 km (Ramesh & Vel 2011). The western coast is flanked by the Bay of Bengal, whereas the coast on the east faces the younger Andaman Sea. The coasts and adjacent shelf areas of the Andaman Group on the western side are fairly straight and gently sloping; by contrast, the coastlines on the eastern side tend to have a relatively steeper slope (Rodolfo 1969). The east coast shows sloping, horizontal and plunging cliffs, strong indentation (deeply embayed) and protrusions of promontories (headlands) into the sea. According to the classification of Inman & Nordstrom (1971), the coasts of the Andaman–Nicobar accretionary ridge compare with those recognized at zones of plate convergence and along a transform fault. Embayed coastlines with valley-mouth inlets as on the Andaman coasts are the result of relatively recent marine submergence superimposed on originally structure-controlled embayed coast.

### Beaches and beach rock

Beaches are the most common coastal landforms in the Andaman–Nicobar Islands and have different mineral compositions

according to the local geology (Garzanti *et al.* 2013). In the Andaman Group, beaches are best developed along the eastern coast; however, there are some sandy beaches on the west coast such as at Collinpur and Wandoor, west and SW on South Andaman (Fig. 1.1), as well as on smaller islands off the west coast of North Andaman (e.g. Point and Paget islands). Betapur beach on Middle Andaman is the longest beach in the Andaman Group and runs for 3 km in an almost straight line, displaying well-developed beach crest (berm) stabilized by sea creepers and trees. There are plenty of beaches of mixed siliciclastic-carbonate (coral fragments) sediments on Havelock and Neil islands, part of Ritchie's Archipelago. Garzanti *et al.* (2013) identified calcareous and palaeovolcanic detritus derived from weathering and erosion of volcanic rocks, reef flats and carbonate-siliciclastic shelves. The curved Radhanagar beach on Havelock Island is about 600 m long and 10–30 m wide, and is classed as a wash-dominated beach (Bird 2008). Bharatpur and Sitapur beaches in Neil Island are also wash-dominated. Corbyn's Cove beach on South Andaman is an example of a dissipative type of beach (Wright & Short 1984; Bird 2008). At this location the acidic to intermediate composition of the lithic grains and overall quartz-rich nature of the sand grains indicate crustal rock sources (Allen *et al.* 2008; Garzanti *et al.* 2013). Shingle beaches are well developed all along the coast near Panchwati in Middle Andaman Island, where ultramafic ophiolite hills occur close to the coast and streams with a short transport distance carry the coarser (>sand grain size) sediments to the coast. Modern sands from the Panchwati beach also show ultramafic source rocks (Garzanti *et al.* 2013).

The term 'beach rock' (a form of beach calcarenite) refers to the calcium-carbonate-cemented beach sands that have turned into hard sandstone layers (Bird 2008). This type of rock results from lithification in the intertidal and spray zones of mainly tropical coasts by alternating wetting and drying of the beach face, which allows daytime solar warming of interstitial water within the porous sands to promote saturation and intrastratal precipitation of calcium carbonate. The importance of beach rocks is based upon three main aspects: their impact upon coastal evolution (Cooper 1991); their significance as former sea-level indicators (Hopley 1986); and their evidence



**Fig. 2.4.** Beach rock from the west coast of Paget Island, offshore North Andaman. This coral-bearing polymict conglomerate is devoid of any internal structure, and contains angular to well-rounded clasts in a poorly sorted matrix of sand, granules and pebbles.





**Fig. 2.5.** Tombolo, 0.6 km long, linking Smith Island with Ross Island (east side of North Andaman). View facing Smith Island.

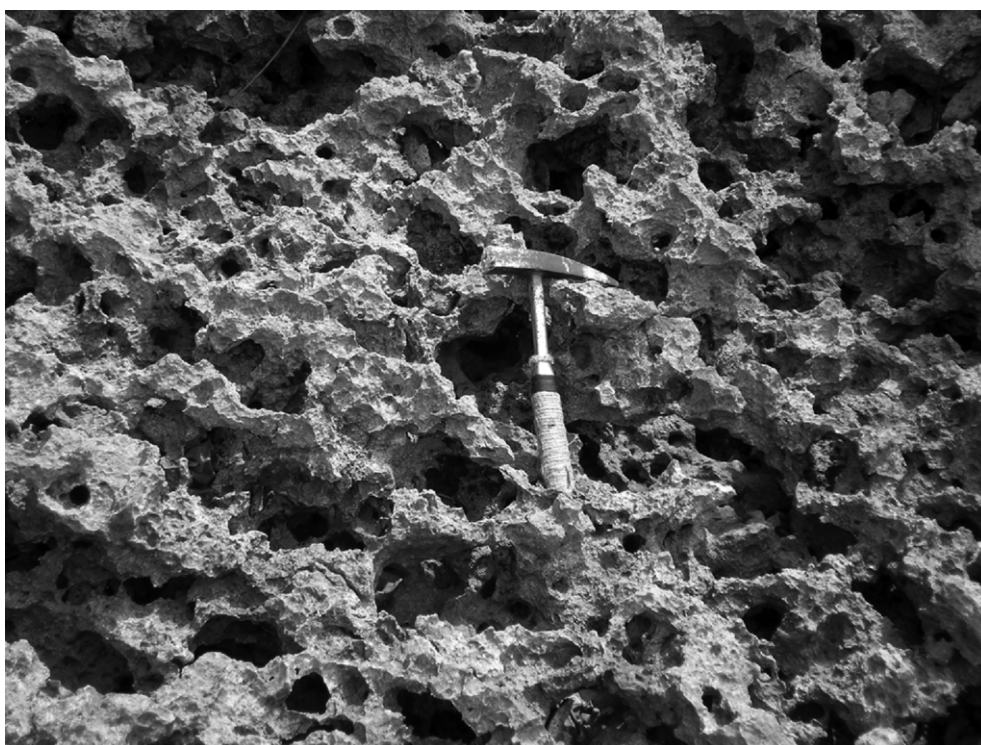
on the process of shallow carbonate cementation (Longman 1980).

Late Quaternary beach rocks are common among the Andaman–Nicobar archipelago and are composed of sandstones, breccias or conglomerates with different proportions of siliciclastic and carbonate grains, cemented by calcium carbonate. Beaches on the Wandoor and Chidiyatapu coast show discontinuous 10–20 cm thick lenses of sheet-like sandstones gently dipping ( $<10^\circ$ ) seawards, whereas beach rock made up of up to 50 cm thick units of weakly indurated and parallel-laminated sandstone beds and coral and shell-bearing conglomerates have been recognized along the coastline of Paget Island. The beach conglomerates are devoid of any internal structure and composed of angular to well-rounded and assorted framework components (sand, granules and pebbles) of different lithologies, including fragments of coral and

bivalve shells (Fig. 2.4). The sandstone beach rocks show widely variable textures and cement fabrics, implying a complex pattern of diagenesis (Vieira & De Ros 2006). Rajshekhar & Reddy (2003) investigated the beach rocks of South Andaman and conducted radiocarbon ( $^{14}\text{C}$ ) dating of constituent shells. Wandoor beach rocks yielded an age of 1540–1350 years whereas Chidiyatapu beach rock proved to be older, yielding an age of 4410–3900 years.

### Tombolo

A tombolo consists of a sand bar joining an island with another island or the mainland. Tombolos come in various forms – single, double, multiple, forked or complex – in response to the prevailing coastal system. For example, a double tombolo



**Fig. 2.6.** Phytokarst (Folk 1973), a type of small-scale solution sculpture, on Neil Island characterized by sharp irregular cockling and numerous irregular pores.





**Fig. 2.7.** Large cavern with speleothems and dripstone curtains inside the limestone cave of Baratang Island.

would result from seasonal fluctuation in longshore drift. Tombolos occur on North and South Andaman islands and are a major tourist attraction (Fig. 2.5). Bandopadhyay *et al.* (2008) first described the geomorphology of a North Andaman tombolo where a roughly north–south-trending tombolo links Ross Island in the south with the Smith Island in the north. This simple tombolo is 0.6 km in length and 3–4 m in width at its middle part during low tides, widening gradually. The ratio of Ross Island’s offshore distance from the Smith Island to its length is 0.75, which ensured that a tombolo and not a salient would form (Woodroffe 2002). The origin of this tombolo may be attributed to the formation of a spit-like barrier by wave refraction around Smith and Ross islands, or by

deposition from longshore current. The source of the sediments appears to be mainly from the beaches of the islands linked by the tombolo, which is rich in biogenic sand and gravel. The presence of a single tombolo connecting two islands off the eastern coast of the North Andaman Island indicates little or no seasonal shift in longshore drift in this part of the Andaman coast. Bandopadhyay *et al.* (2008) pointed out that before the 2004 tsunami the two islands were separated during high tide, allowing boats to cross over the submerged sand bar (tombo-lini). After the 2004 tsunami, during normal high tides the sand bar remains an emerged sand body (tombolo) joining the two islands. Only during neap tides does a small portion of the middle part of the tombolo become flooded.



**Fig. 2.8.** Coral reef exposed at Interview Island, off the west coast of Middle Andaman Island. The 26 December 2004 earthquake uplifted the reef by 2 m and left it permanently stranded above present-day high tide. The old beach (left) is now some 80 m inland from the present high-tide line.





**Fig. 2.9.** An aerial view of the fringing reefs surrounding the Cinque Islands located south of Rutland Island, South Andaman.

### Karst landforms

The western coast of Neil Island exposes thick and relatively homogeneous Pleistocene limestones (chalk) that form an east–west-trending steep cliff and vast areas of subhorizontal carbonate shore platform fully exposed at low tide. The cliff section at its western end shows a natural arch attached to the headland. The bare rock surface of the seawards-sloping homoclinal carbonate shore platform displays karstic features, the dimensions of which range from millimetre-scale dissolution pits and grooves on limestone surfaces to underground caves. Phytokarst (Folk 1973), a type of small-scale solution sculpture, on Neil Island chalk surfaces is characterized by sharp irregular cockling and numerous irregular pores (Fig. 2.6) formed by weathering, dissolution and biogenic corrosion in the meteoric environment. Labourdette *et al.* (2007) considered that karst formation is intrinsically tied to the

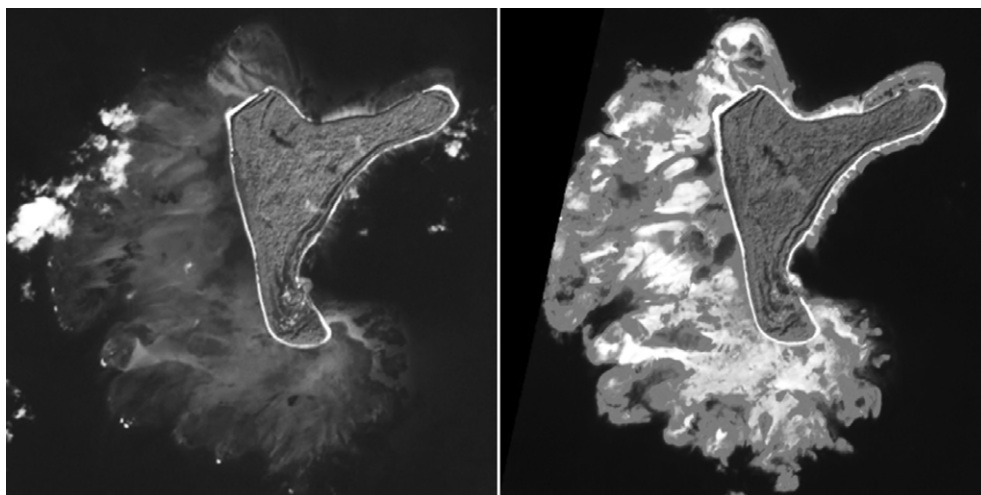
presence of a freshwater lens in order to dissolve the carbonate rocks, likely during sea-level lowstands. The limestone caves on the SW side of Baratang Island (12° 05' N, 92° 45' E) contain speleothems. Dripstone curtains a metre or more in length are seen hanging from the ceiling, and pillars of stalagmites grow above the ground (Fig. 2.7). Radiocarbon dating and  $\delta^{18}\text{O}$  analyses of these stalagmites have been used to provide a 4 ka record of variation in the Indian Summer Monsoon (Laskar *et al.* 2013).

### Coastal terraces

The 2004 Sumatran earthquake caused metre-scale co-seismic uplift along the western coast of the Andaman–Nicobars and subsidence along the eastern side. Along the west coast of Interview Island, Middle Andaman, fringing coral reefs were



**Fig. 2.10.** Coral and coral-algal reefs developed on a phytokarstic shore platform on the coast of Neil Island.



**Fig. 2.11.** A pair of Terra Satellite images of North Reef Island, North Andaman before (left) and after (right) the 2004 earthquake. The post-earthquake image shows how the reefs have been lifted permanently out of the sea. NASA Earth Observatory.

uplifted by 2 m leaving the reef permanently stranded above present-day high tide (Fig. 2.8). Such displacements have happened in the past, and radiometric dating of dead coral reefs from raised marine terraces have been used to gain insights into the frequency of such events. A study by Awasthi *et al.* (2013) compared radiocarbon age data from coastal fossil coral terraces on Interview Island, Hut Bay on Little Andaman, Port Blair and North Cinque Island, South Andaman with terraces on the east coast of Lamiya Bay, North Andaman Island and the west coast of Havelock Island. The oldest and best-developed series of terraces were found on Interview Island at elevations of 50, 26, 18, 13 and 7 m above sea level with  $^{14}\text{C}$  (BP) ages that range from  $30\,880 \pm 300$  to  $6977 \pm 85$  years. While the study found evidence of 14 major seismic events since *c.* 40 ka BP, most of the landscape-changing events took place after 9 ka, suggesting that the frequency of major earthquakes ( $M > 7$ ) in the region has increased during the last 9 ka. The results also showed that the pattern of uplift and subsidence seen in the 2004 earthquake has been a continuous feature in the past, especially the subsidence of South Andaman.

Other examples of terraces can be found on Paget Island, where horizontally stratified beds of hard beach rock (sandstones) up to 60 cm thick occur well above the present-day intertidal zone. Marine notches in the lower part of an agglomerate cliff exposed above present-day high-tide level on the coast near Panchwati, Middle Andaman indicate past erosion by sea waves. Occurrence of beach material on higher ground inside the coast was described as raised beach by Karunakaran *et al.* (1964, 1968).

### Coral and coral reefs

Late Paleocene patch reefs interstratified with volcanoclastic sandstones have been identified on the Rampur coast of Middle Andaman Island (Bandopadhyay 2012, fig. 8b), and similar-aged limestone deposits interpreted as bioherm and biostroms are found at Tugapur of Middle Andaman (Ray 1982). The modern reefs date back to the Holocene and cover about  $2000\text{ km}^2$  or 6% of the islands. The modern Andaman–Nicobar archipelago contains a rich diversity of coral reefs dominated by fringing reefs (Fig. 2.9) and a long barrier reef (329 km) on the west coast. On the western side of South and Middle Andaman lies a 4 m deep lagoon, separated by an 80 m deep channel (Saxena *et al.* 2008).

Studies on the taxonomy of Indian coral reefs began as early as 1847 by Rink in the Nicobar Islands; since then over 200 coral species have been identified. Andaman has at least 135

species (59 genera) of stony corals, of which 110 species and 45 genera are hermatypic. Thirty-two genera are known from Great Nicobar, and new species are being discovered each year (Mondal *et al.* 2011; Mondal & Raghunathan 2013). *Porites* spp. is dominant in the northern and southern Andaman islands, whereas *Acropora* spp. is the most common in the Middle Andaman and Nicobar islands. The soft corals *Sarcophyton* and *Lobophytum* are common throughout the islands. Coral growth tends to be richer on the western coast, and the Nicobar Islands are richer than the Andaman Islands.

The coral and coral-algal reefs occur in nearshore shallow-marine shelves and in small pools developed on a phytokarstic shore platform such as the Pleistocene chalk formation of Neil Island (Fig. 2.10). Such rock substrates are widely perceived as optimal substrates for reef initiation and growth due to their stability and elevation above the seafloor. A terrigenous muddy sand is typically found beneath most leeward fringing reefs, grading up into a rubble facies and then to a relatively thin framework cap. The fringing coral reefs in the islands of Andaman–Nicobar may be classified as: (1) headland-attached fringing reef; (2) bay head fringing reef; and (3) narrow beach base reef.

The reefs of the Andaman and Nicobar islands are the most pristine reefs remaining in India, but are under threat from both human activity and natural disasters. The 26 December 2004 tsunami led to extensive destruction of coral reefs, mainly due to uplift of land areas in the western part of the archipelago. Figure 2.11 shows an example of the dramatic changes that took place on North Reef Island off the west coast of North Andaman caused by uplift during the 2004 earthquake (discussed further in Chapter 10).

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